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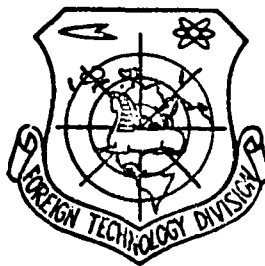
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THE ANNUAL REPORT OF THE INSTITUTE OF ATOMIC ENERGY

INTENSE FLOW ELECTRON PULSE ACCELERATOR

Wang Nie Yen

Preface

In order to strengthen the scientific and technical interchange, it was decided to publish "the Annual Report of the Institute of Atomic Energy" (ARIAE). This issue mainly introduces the progresses in scientific research and production as well as the situation of academic exchange of our institute in 1979 (from Jan. 1 to Dec. 31). IAE, situated in the south-western suburbs of Beijing, is a multidisciplinary institute of nuclear science. Its predecessor was the Institute of Modern Physics of the Chinese Academy of Sciences, which was founded in 1950. It was renamed the Institute of Atomic Energy in 1958. The famous nuclear physicists, the late Prof. Wu Youxun and Prof. Qian Sanqiang had been the directors of this Institute successively. The director today is the well-known nuclear physicist, Prof. Wang Ganchang.

At present, the main fields of scientific research in the IAE are, nuclear physics, accelerator, radiochemistry, radiochemical engineering, reactor, isotopes preparation etc. There are 21 laboratories in the Institute. The main facilities in IAE are, a heavy-water research reactor, a swimming-pool light-water reactor, three accelerators, two 180° electromagnetic separators, several zero-energy reactors and various kinds of hot cells used for the examination of irradiated reactor materials, the nuclear fuel reprocessing and the production of radioactive isotopes. Besides these, a linear electron accelerator with high current and short pulse is under construction. A tandem accelerator, type HI-13, will be imported from abroad as well.

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This issue consists of 10 parts. Abstracts of over 310 articles are presented. It can be summarized as follows.

1. In the research on basic science and the fundamentals of applied science, some noteworthy progress has been made. For example, by using a home-made semiconductor detector spectrometer with a magnetic analyzer for particle identification at Van de Graaff accelerator, the intermediate structure in nuclear reaction has been studied and a possible intermediate resonance with a width of about 200 keV was discovered in the excitation function of $^{28}\text{Si} (d, p) ^{29}\text{Si}$ reaction at $E_d = 1.90$ MeV. After detailed measurement and analysis, a gross structure in the excitation curve of the $^{115}\text{In} (n, n') ^{115m}\text{In}$ reaction around $E_n = 2.7$ MeV was observed. Combining with the experimental investigation, the quasi free cluster knockout reactions in ^6Li were analysed with DWIA and PWIA. The results indicated that the DWIA is superior. A calculation based on the preequilibrium emission model with exciton-phonon coupling gives good agreement with our experimental data in the radiation capture cross section of fast neutron on ^{235}U , ^{56}Fe and ^{208}Pb . A work about the relation between the quark-quark interaction and the nucleon-nucleon interaction was initiated. Research on the inertial confinement for nuclear fusion with charged particle beam has been developed. The physical design and the preparation of some components for high current electron LINAC have been performed.

The work of compilation, evaluation and measurement of nuclear data has moved forward. The evaluation of neutron data in the resonance region and the data of γ -ray production have been undertaken. The nuclear data library about the fission yields has been tentatively established on a NOVA-840 computer and the automatization of evaluation has been realized. The first batch of group constants for thermal reactor has been produced as well.

Using the method of functional analysis, we have already investigated the dominant eigenvalue of the neutron transport operator for the energy-dependent physical system which has the isotropic scattering and/or fission and contains the cavity. In this year, by suitable mathematical treatment we have proved the existence of the dominant eigenvalue of the neutron transport integrodifferential Boltzmann operator for the case of the anisotropic scattering and/or fission. Thus we have solved one of the basic problems in the neutron transport theory.

In 1979, the accuracy of the burnup measurement of the fuel element was improved by means of a variety of methods including quantitative

analysis of many fission fragment elements. An extraction process featuring the extraction of the transplutonium elements, Np, Am, Cm and the fission fragment elements Tc, Sr, Cs, Pu etc. from high level radioactive waste water was suggested. Study of the adsorption property of a new synthetic thiourea chelate resin on the noble metal ions indicated that it can be used for the simultaneous trace determination of seven noble metal elements, such as Pd, Au, Pt etc. Besides, study on the application of crown compounds to the separation and analysis has been initiated.

For experiments in reactor physics, after completing the investigation in the pulsed neutron source technique, particular emphasis was laid on the research of statistical technique and measuring the in-core neutron spectra. The precision in measuring the heat transfer of gas flow in pipes at high temperature difference and that of sodium in distorted structure was improved. The determination of the heat conductivity of UO_2 pellet, the study on the creep of the uranium-aluminum alloy fuel element and the running water corrosion test were carried out and better results were obtained.

For medical protection research, study on the chromosome aberrations of human lymphocytes induced in vitro by neutron irradiation has been pursued.

2. Advances in the applied research serving to the national economy. For example, a prototype oil logging device based on the measurement of inelastic scattering γ -ray spectra induced by neutrons had passed the field test. Its ability in discriminating oil layers from water layers makes it an advanced measuring tool for oil prospecting and exploitation. An zirconia solid electrolyte analyser (type ZO-101) based on the practical equation, suitable for the on-line analysis of oxygen concentration in a pure argon or nitrogen system, achieved better sensitivity and accuracy. This project won the third prize of invention awarded by the People's Republic of China.

Besides, a lot of new isotopes have been developed. Study on extraction of ^{99}Mo - $^{99\text{m}}\text{Tc}$ generator, ^{132}Tc - ^{132}I generator and ^{133}Xe physiological saline injection from fission products of ^{235}U has been completed. Since their quality has come up to the international standard, they are put into production and supplied to various customers at present. Over 10 new varieties of labelled organic compounds and three new types of radio-immunoassay kits in vitro have been tentatively supplied to medicine circles. In respect of radioactive source, the new assortments, such as ^{59}Fe disc

sources, ^{238}Pu and ^{241}Am annular sources were added to the catalogue of commodities.

Study of the neutron transmutation doping (NTD) on silicon by reactor was initiated.

In brief, the applied research for the national economy now becomes an important domain of our Institute.

3. Some experimental facilities have been constructed, reconstructed or extended and some electronic equipments have been prepared. The out-of-dated heavy water research reactor was put into reconstruction. The disassembly of the reactor, the lifting up and burial of the old reactor vessel, putting the new vessel to the right position and the mounting of equipments and piping systems have been safely carried out. As a result of close coordination of various departments and the adoption of a series of effective steps, the disassembly of the reactor was performed safely and smoothly. Moreover, a wealth of experiences in the disassembly of a reactor and the operation under intense radiation fields has been accumulated. It is expected that after the reconstruction, the maximum thermal neutron flux per unit power will be raised by 50%, the usable in-core space for irradiation will be increased by 2.6 times and the excess reactivity will be increased by 3%, so it will be more suitable for comprehensive uses of the reactor, such as radioactive isotope production, various physical experiments, NTD silicon irradiation and fuel element testing. In the preparation of the prototype high current and short pulse electron LINAC, achievements have been obtained for the short pulse electron gun and the adjustment of the cavity type coupler. The phase measurement, the power transmission of microwaves and the mounting of various assemblies before the bunching section were completed. The beam current was extracted while there was accelerating electric field in the bunching section and the picture of high current was presented. Due to the close cooperation between theorists and experimentalists, many difficulties were overcome. The improvement of the cyclotron continued in 1979. The speed and the precision in magnetic field measurements were raised by means of an home made automatic magnetometer. In the field of computer technology, a home made digital computer of model TQ-6 in the rank of $10^6/\text{s}$ was successfully installed and adjusted, and officially put into operation early in November, 1979. Besides, we have adopted measures to extend the application of the swimming-pool light-water reactor, such as the production of radioactive isotopes Cr, P, Mo-Tc etc, activation analysis and some nuclear

physics experiments. In the field of nuclear electronics, a photographic recording oscilloscope for single pulse and the interface of 1024 multichannel analyzer with a table computer of model "Great wall 203" were set up. A data acquisition and processing system based on a computer passed the test for separate single-user terminal. The preparation of the standard NIM plug-in units and the study of the CAMAC system moved forward. In order to extend the production of radioactive isotopes, a new building for producing and testing isotopes was nearly completed.

In 1979, the academic exchange was quite active. In our Institute, after the symposium on nuclear physics in 1978, symposiums on reactor, chemistry, mathematics, detectors and nuclear electronics, electrophysics and radiation protection were successively held early in 1979. There were 398 articles presented in these symposiums. The number of various conferences, meetings and symposiums that we took part in totalled 259. The international academic exchange also became increasingly strengthened in this year; 98 foreign friends visited our Institute and 54 lectures and discussions were held. These academic pursuits enlivened the academic atmosphere, promoted the academic exchange and improved the friendship between scientists from different countries.

In consequence of the lack of experience, shortcomings and mistakes in this Annual Report are unavoidable, so advices and criticisms are surely welcome.

Editor

INTENSE FLOW ELECTRON PULSE ACCELERATOR

by

THE CHARGED PARTICLE INERTIA CONTROL RESEARCH GROUP

Translated from 1979 Inst. of Atomic Energy Annual Report, Beijing, P.R.C.

CHAPTER 6. INTENSE FLOW ELECTRON PULSE ACCELERATOR

1. The physical and engineering designs of the intense flow electron pulse accelerator.

(by charged particle inertia control research group)

The main objectives of the intense flow electron pulse accelerator are as follows:

electron energy	1 MeV
electron beam flow	80kA
pulse width	70ns
beam flow energy	5.6 kJ
beam flow power	$8 \times 10^{10} \text{ W}$

When the diameter of the focal point of the electron beam is $\sim 1.5 \text{ mm}$, the beam flow power density is $4.53 + 10^{12} \text{ W/cm}^2$. The structure of the accelerator is schematically shown in Figure 1.

The major parameters of the intense flow electron pulse accelerator are as follows:

1. Excitation voltage generator

total electrical inductance	15 μH
output electrical capacitance	35 nF
electrical charging frequency ω of the transmission wire from the bombardment voltage generator	$2.013 \times 10^6 / \text{s}$

ii. Water-medium double-layer coaxial transmission wire:

maximum charging voltage	1.12 MV and 1.21 MV
internal wire resistance	4.217 Ω
external wire resistance	2.17 Ω
transition section resistance	6.474 Ω
internal wire capacitance	8.48 nF
external wire capacitance	22.6 nF
electrical length of transmission wire	70 ns
outer diameter of inner cylinder (diameter)	48 cm
inside diameter of the middle cylinder	90 cm
outside diameter of the middle cylinder	91 cm
inside diameter of the outer cylinder	126 cm

iii. Main switch

distance between electrodes	~ 2 cm
maximum electrical field in the main switch	0.54 MV/cm
inductance of the main switch	~ 14.9 nH

iv. The diode

diode resistance	~ 6 Ω
diode capacitance	~ 32.9 nF
diode inductance	~ 35.5 nF
electron beam rising time	~ 25 ns

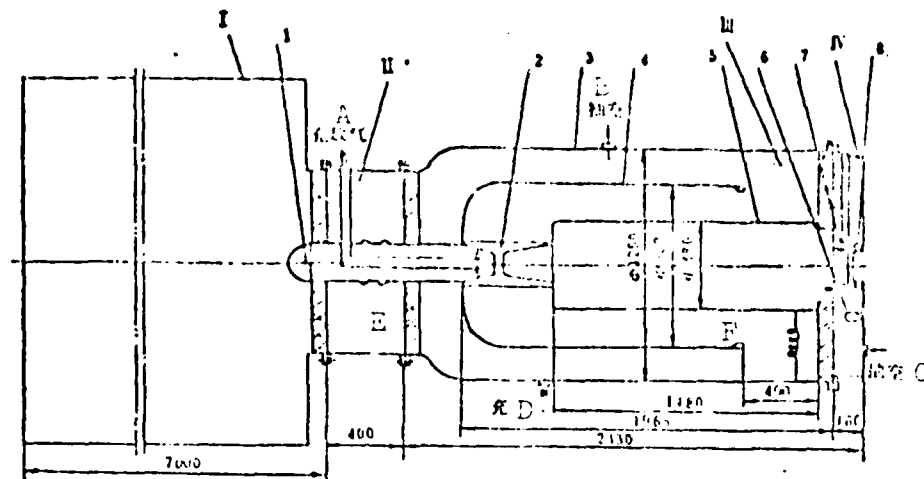


Figure 1. The structure of the intense flow electron pulse accelerator.

a--gas filling and evacuation; b--evacuation; c--evacuation;
d--water filling and evacuation; e--oil; f--water

- | | | |
|--------------------|-----------------------------|------------------------|
| 1. wiring board | 5. inner cylinder | I. Marx generator |
| 2. main switch | 6. integration ring | II. transition room |
| 3. outer cylinder | 7. preliminary pulse switch | III. transmission line |
| 4. middle cylinder | 8. Zokovsky ring | IV. diode |

A. Excitation voltage generator

It is composed of 20 $0.7 \mu\text{F}$ capacitors. When the charging voltage is 70 kV, the energy stored in the bombardment voltage generator is 34.3 kJ. The output capacitance of this excitation voltage generator is 35 nF. The positive-negative direct current charging method is adopted. The number of sphere gaps is 10. Capacitors, sphere gaps, charging resistors and grounding resistors are all immersed in a large oil tank which is filled with 30 tons of transformer oil.

The circuit diagram of the excitation voltage generator is shown in Figure 2. Between the first and the second sphere gap, an external triggering method is used. From the third pair to the

tenth pair of sphere gaps, it relies on the penetrating voltage to sequentially break them through.

The total inductance of the excitation voltage generator is 14.3 μH which includes the inductance of the connecting wire 8.83 μH . The charging time of the excitation voltage generator with respect to the transmission line is about 0.9 μs . It is advisable to minimize the electrical inductance of the excitation voltage generator in order to reduce the charging time for the transmission wire, to increase the pressure resistance capability of the transmission wire, and to reduce the energy loss from the water medium of the transmission line (the time constant of leakage through the water medium is 7 μs). Improving the quality of the pulsing capacitors, reducing the volume, and to minimize the inductance of the connecting wire are the important ways to reduce the inductance of the excitation voltage generator. A resistance network simulation method was used to calculate the values of break through voltage for each sphere gap.

B. Water-medium double-layer coaxial transmission wire

Using the excitation voltage generator to charge the double-layer coaxial transmission line by harmonic oscillation charging, the efficiency of energy transmission can be raised. In the physical design of the accelerator, a computer is used to obtain the numerical solutions using the Laplace transformation method and the state equation method respectively for the accurate determination of the voltage transmission efficiency as well as the energy transmission efficiency.

As for the consideration of the insulating voltage endurance and the geometric dimension of the transmission line, it primarily follows the electrical break through equation in the water medium [1] to select the diameters of the inner, middle and outer cylinders in the transmission line in order to ensure that the actual

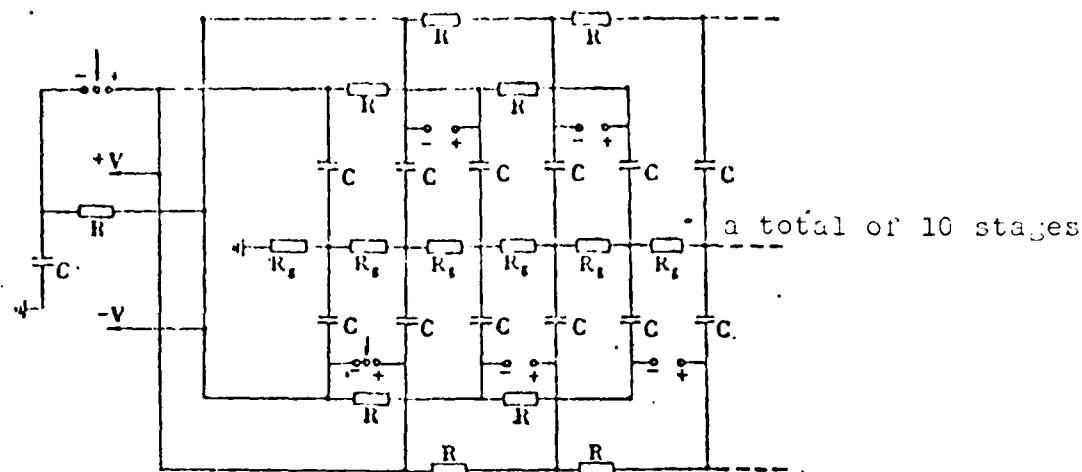


Figure 2. Basic principle schematic diagram of the excitation voltage generator

field strength at any point inside the transmission line is less than the allowed field strength plus a sufficient safety coefficient (see the K value in Table 2). We have carried out an optimal parametric calculation using the computer with regard to the requirements of the combined voltage endurance, voltage transmission and energy transmission.

The major field strength parameters in the design of the transmission line are listed in the table below. The field strength of the transmission line is calculated using a network method by a TQ-6 electronic computer. The emphasis was especially placed on the study of the distribution of electric field near the end of the middle cylinder and the beginning of the outer cylinder. Furthermore, special arrangement was made to modify the shape of the end of the middle cylinder and the head of the outer cylinder to raise the voltage endurance of the transmission wire.

The cylinder support material in the transmission line is the gold red stone ceramic. Its dielectric constant $\epsilon = 75-80$.

It was experimentally obtained that its voltage endurance in water is 12 kV/mm with respect to a cross wave pulse with a rising time of 2 μ s. Because its dielectric constant is very close to that of water (81), the effect of the support material on the propagation of electromagnetic wave in water can be minimized.

Under the short pulse high voltage condition, water is a relatively ideal transmitting medium. Deionization process must be carried out to ensure that the resistivity of water is larger than 1 M Ω cm. The deionization system provides 0.5 tons of water per hour. In order to prevent bubble formation due to air originally in the transmission wire during the injection process of water into the transmission wire which makes the electrical break through much easier, gas evacuation procedure was adopted before water injection into the transmission wire.

C. Sphere gap and main switch

The material of the spark sphere gap outer cylinder is nylon 6. The outer diameter of the tube is 150 mm, inner diameter is 110 mm and length of the cylinder is 300 mm. The design of the shape of the sphere gap electrode is mainly to assure that there is a uniform electric field area at the center of the sphere gap. For this the tips of both electrodes must have a plateau area. The TQ-6 computer was used to compute the electric fields under various conditions of the diameter of the plateau and the radius of curvature from the plateau tip to the rear of the electrode. The electrode material of the sphere gap tip is stainless steel or a copper-tungsten alloy. The sphere gap is filled with 1-4 atmospheric pressure of N₂ or a gas mixture (90% N₂ and 10% SF₆).

At various electrode distances, the relation between break through voltage and the gas pressure is plotted.

In order to reduce the inductance of the main switch, it is filled with 10 atmospheric pressure of SF_6 gas to decrease the electrode distance.

D. Diode

The designed resistance of the diode is 6Ω . Because the resistance of the transmission line is 6.47Ω , a 6Ω resistance for the diode is ideal from the energy transmission efficiency point of view. Considering the self-constriction of the electron beam, it requires a higher v/γ ratio for better performance. The optimal diode resistance may be lower than the matching resistance. This can be obtained by changing the distance between the cathode and the anode. The cathode of the diode was experimented using several types of shape and structure. It included needle shaped cathode, solid cone cathode, hollow cone cathode, etc. The materials used were tungsten, graphite, bronze and stainless steel. The material and thickness of the anode will be determined by future physical experiments. At this moment, the design adopted the use of 2-6 mm thick aluminum plate for testing.

The diode used a radical insulation arrangement. An 8 cm thick organic glass plate was used to separate the deionized water and the vacuum zone. The outside diameter of the insulating plate was selected to be 2.72 times that of its inner diameter. The maximum value of field strength exerted on the inner diameter of the insulating plate is 45 kV/cm. This is much lower than the voltage endurance strength for organic glass reported in the literature. From the angle of voltage endurance, it is very reliable.

In order to control the reaction of the pulse to the diode, a section of organic glass is inserted in the conducting rod of the cathode. Its length can vary. Through the capacitive voltage divider, the magnitude of the pulse can be adjusted. When the main pulse reached the section inserted by the organic glass, it

1 Blumlein 传输线设计的电场参数

	充电电压, 2 MV	电极面积, 3 cm ²	实验场强 E, 4 kV/cm	允许场强 F, 5 kV/cm	$K = \frac{E}{F}$
6 内筒外表面	0.09	17500	60.2	141.2	0.568
7 中筒内表面	-1.12	46600	42.7	257.2	0.166
8 中筒外表面	-1.12	47500	76	257.6	0.285
9 外筒内表面	0	72400	55	125	0.44
10 中筒末端处		5330	108	314	0.344

11 * 允许场强 F 值是按 J.C. Martin 公式, 在有效充电时间 $t_{eff} = 0.6 \mu s$ 时计算得到的。

1--electric field parameter of Blumlein transmission line design; 2--charging voltage; 3--electrode area; 4--experimental field strength E; 5--allowable field strength F; 6--outside surface of outer cylinder; 7--inside surface of middle cylinder; 8--outside surface of middle cylinder; 9--inside surface of outer cylinder; 10--end of the middle cylinder; 11--the allowable field strength value F is obtained using J. C. Martin equation within an effective charging time $t_{eff} = 0.6 \mu s$.

is conducting through surface discharge.

The electric field distribution and electron trajectory inside the diode have been calculated in the computer.

E. Physical measurement of the electron beam parameters

Resistance voltage divider and capacitance voltage divider were designed to measure the high voltage pulse in the diode, in transmission wire, and at the output end of the excitation voltage generator. In the meantime, design and modification were made to use Zokovsky coil, integration ring and current divider to measure the current in the diode and the return current.

Prototype experimental apparatus to measure current and voltage as described above which can be used on small transmission lines has been designed.

The various parts of the accelerator are in the process of being fabricated.

(written by Wang Nie Yen)

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2. The calculation of electrical field of Blumlein transmission line

Kung Fong, Yang Da Wei, Wang Shu Moa and Wang Nie Yen

The basic method used in the calculation of electric field is the square network super relax iteration method. Using the difference equation format in the Laplace equation in the axial symmetric cylindrical coordinate system, the solution is obtained using iteration at the network matrix point. The iteration was realized in a 129×561 matrix. A method similar to the one used by J. E. Boers [1] was used to treat the difference equation on the interface of different media. We also deduced the difference equations at different intersecting points at the interface.

Using the program compiled with BCY language, the calculation was carried out on a TQ-6 computer. The program can directly output the coordinates of equi-potential lines. The equi-potential value is determined in steps of 5% of the potential between the two electrodes. The program also has the capability to directly use the wide outputter printer to plot the distribution of equi-potential lines. It is also capable of magnifying the portion of area in the equi-potential distribution diagram which is of interest.

The calculated result indicates that when the effect of the switched is not considered, the field strength at the end of the middle cylinder is the highest among the electric field strength in the entire region. We chose various ends of different shapes which made the electric field strength at that point to drop from 177 kV/cm to 108 kV/cm. The electrical field distribution of the entire region (no main switch) is shown in the figure.

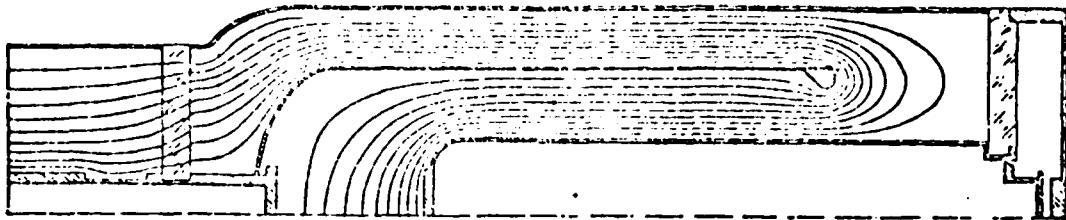


Diagram of electric field distribution of the whole region

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